Electro-Optic Propagation

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LONG-TERM GOALS

1) The development and testing of a comprehensive infrared and optical propagation assessment model suite for the marine atmospheric boundary layer.
2) The improvement of weather-dependent range predictions for the Target Acquisition Weapons Software (TAWS) in the marine environment by developing a near-field wake effects, by modeling the residual far-wake effects (ship tracks) to provide a means of early detection of ship targets, and by developing algorithms to handle horizontal line-of-sight (HLOS) scenarios to extend the capabilities of TAWS to surface and low altitude situations.

OBJECTIVES

The electro-optical propagation objectives are:
1) The development of EOSTAR, an end-to-end model development for infrared and visible absorption, scattering, refraction, and scintillation using local meteorological input data.
2) The acquisition and analysis of mid-wave and long-wave infrared transmission and scintillation data in a well-characterized marine atmospheric surface layer, over typical maritime ranges of 7 to 15 kilometers;
3) The improvement of naval marine target modeling in TAWS by adding the effects of the near-field wake to the boat and ship target and background models.
4) An early IR detection task to predict the radiance contrast and persistence of the residual far-wake. Modeling the far-wake will give TAWS the capability of providing range estimates of the ship tracks remaining in the water from ship movements. This will make early detection possible, because the ship track points to the ship target.
5) A horizon line of sight task to overcome the limitation in TAWS that only permits a single flat surface background. TAWS does not allow sky or mixed backgrounds. This task will make sky radiance values available from MuSES and a capability for mixed sky and coastline backgrounds to supplement the present SeaRad ocean background.

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APPROACH

The central organizing work effort for the infrared propagation task is the creation of a model suite, which will accurately predict propagation from source to sensor, or from source to target. A close collaboration between SSC San Diego and TNO (Netherlands) is responsible for the development of a new propagation assessment tool called EOSTAR (Electro-Optical Signal Transmission and Ranging). The goal of the EOSTAR project is to develop a stand-alone PC-based computer code with a user-friendly interface, and fully user-definable input parameters.

The EOSTAR development at TNO Physics and Electronics Laboratory, The Hague, The Netherlands is performed by Dr. Alexander van Eijk and Mr. Gerard Kunz, and Dr. Steve Doss-Hammel and Dr. Dimitri Tsintikidis are co-developing EOSTAR at SPAWAR Systems Center San Diego.

The near wake task is developing algorithms that model the wake effects of the displacement hull ship, the Research Vessel Point Sur. The NRL KELSEA model provides the skeleton model from which the centerline turbulent wake, the bow and stern breaking wave, and the Kelvin system are modeled for a wind-driven random sea.

The early ship detection task is based on modeling the far wake. Several factors affect the far wake production and persistence, including sea state, ship displacement, ship speed and propulsion system. Surface wind velocity, surfactant concentration, temperature profile and turbulent mixing affect wave dampening and surfactant redistribution. Only after the surface chacterization from these hydrodynamics effects are modeled, can the infrared radiance reflected from the atmosphere and emitted from the sea surface be determined. The approach, therefore, is to characterize the surface hydrodynamics effects for a displacement hull vessel in 2003 and include an infrared radiance model in 2004. The displacement hull model will be demonstrated in TAWS in 2004 for an FFG (450 ft., 4100 loaded tons) and a DDG (510 ft., 9200 loaded tons).

The horizon line-of-sight task employs a geometric approach using the sky radiance module of the SeaRad ocean radiance model, currently in TAWS. The land backgrounds in MuSES will be made geometrically dependant and capable of combined sky and coastline radiance calculations. After proof of concept in MuSES a 6.4 transition will be proposed to modify TAWS to provide the terrain parameters and view angle parameters.

WORK COMPLETED

There were two primary completed elements for the infrared propagation task. First, the analysis of data from the Rough Evaporation Duct (RED) Field Experiment was a primary component of the work effort for the current year. The test geometry probed a typical anti-ship cruise missile scenario, which features an incoming missile at 2-3 m above surface and a sensor/tracker at 13-20 m above the sea surface.

The second completed element for the infrared propagation effort was the release of version 1.0 of the integrated model EOSTAR (**E**lectro-**O**ptical **S**ignal **T**ransmission and **R**anging) to predict the performance of electro-optical (EO) sensor systems in the marine atmospheric surface layer has been developed. The model allows the user to define camera systems, atmospheric conditions and target characteristics, and it uses standard (shipboard) meteorological data to calculate atmospheric effects such as refraction, turbulence, spectrally resolved transmission, path- and background radiation. Alternatively, the user may specify vertical profiles of meteorological parameters and/or profiles of atmospheric refraction, either interactively or in data files with a flexible format. Atmospheric effects can be presented both numerically and graphically as distorted images of synthetically generated targets with spatially distributed emission properties. EOSTAR is a completely mouse-driven PC

Windows program with a user-friendly interface and extended help files. Most calculations are performed in real-time, although spectral transmission and background radiation calculations take up to a few seconds for each new meteorological condition. The program can be used in a wide range of applications, e.g., for operational planning and instruction.

The initial design requirement has been to drive the EOSTAR program from simple input parameters: standard meteorological data that is available shipboard, and the particular properties of the camera system. The first stage of the simulation then provides the solution of a number of micrometeorological models for the evaluation of the vertical profiles of temperature, humidity, and air pressure in the marine surface layer, as well as refraction and turbulence parameters. Subsequently, these data are used to calculate ray trajectories that simulate the instantaneous field-of-view of the individual camera pixels and which allow the assessment of atmospheric distortion, spectrally resolved path-integrated transmission, path- and background radiance, and optical turbulence.

In the second phase of the project, a module has been added to allow the user to define targets in the scene. The user may control the geometry and radiative properties of the target in order to simulate realistic targets. It is now possible to simulate images as seen by the sensor both with and without atmospheric effects.

For the near wake task, we completed test and evaluation of the displacement hull near wake model using field data collected on the R/V Point Sur and algorithms to reduce runtime were implemented. The results were presented and published at the 2003 BACIMO conference in Monterey. The initial planing hull wake model was completed for the Boghammar patrol boat and a 24-foot speedboat. The development of the planing hull model made it possible to add the SEAL team Mark V and rigid-hull inflatable boats as new targets using the 6.2/6.4 RTP funding.

A feasibility study and approach was published for the early ship detection task. The initial CFD model runs were completed for the FFG and DDG. The SAR algorithms have been modified to incorporate meteorological parameters and the CFD wake data to characterize the surface. The MODTRAN 4 and sky model upgrades were completed for the HLOS Task and the terrain algorithms are established and ready to code.

RESULTS

An analysis and a report on the infrared propagation experiment conducted during the Rough Evaporation Duct (RED) field experiment was completed. Results of the experiment were presented at a SPIE conference, and at the annual AMS conference. The key results:

1. Sea surface roughness affects more than the RF signal: it also modifies IR propagation. We found that the rough surface cut-off of the mirage ray reduces the expected sub-refractive geometric gain to a neutral condition, and hence reduces the overall signal.

2. This test highlights a region where the mean condition is low IR transmission: a) The high temperature and humidity drives a large molecular extinction; b) Sustained moderate winds induce a moderate-to-high aerosol extinction, and also create a sea state causing the reduction of geometric gain to a neutral factor; c) The results have a definite impact upon plans for the use of an IRST system, or high energy laser (HEL) weapons system.

3. ANAM is better than NAM. ANAM does a better job at approaching the low transmission values observed, but the aerosol models under-estimate extinction: the parameterization for ANAM may still need tuning. A comparison with aerosol particle counter data and infrared propagation showed that all data was within a 'factor of 2' which is a good result. The under-estimate of the extinction by ANAM is also consistent with other comparisons. Finally we note that further parameter tuning may well be

warranted: there is a possibility that ANAM (a parametric model) may be biased toward North Sea-type conditions.

4. The under-estimate of extinction along the infrared path utilizing the FLIP-based aerosol measurements is not a surprise since the aerosol particle counts were performed at 20 m height. This is well above all portions of the IR path, which ranged from 2 m to 12 m heights.

5. 'Last' kilometer surf-generated aerosols could be a significant factor (Tony Clarke, U. Hawaii) – but we don't have enough data to test this hypothesis.

A core project to develop and integrate a comprehensive propagation assessment toolbox has resulted in the release of EOSTAR (Electro-Optical Signal Transmission and Ranging) version 1.0. The EOSTAR modeling suite will encompass all of the individual component models necessary for a full source-to-sensor signal intensity prediction for visible to infrared wavelengths. An initial review of the simulation capabilities of EOSTAR was presented at the combined IEEE-APS-URSI conference in Columbus, Ohio, June 2003, and the public release of the model occurred at the Battlespace Atmospherics and Cloud Impacts on Military Operations (BACIMO) conference in Monterey, CA in September 2003.

Results generated by EOSTAR have been compared with theoretical and experimental data available from literature. First, the default bulk micrometeorological model was tested[1] and it was shown that the results are in excellent agreement with earlier published data[2]. Subsequently, the performance of the ray tracer and the module that generates synthetic images of point sources was compared with experimental data available from literature[3, 4, 5, 6, 7, 8, 9] to verify horizon, mirage images, and maximum intervision ranges. This comparison shows that there is a very good agreement between the experimental results and the same data generated by EOSTAR on the basis of bulk meteorological data. The ray trajectories or the observation paths of the camera pixels, which are derived from the vertical profile of the atmospheric refractive index, as well as the atmospheric transfer functions, constitute a second output type that is quite useful for visualization and target identification. A frigate in an atmosphere-free environment is compared to the same vessel seen in a typical sub-refractive marine environment in figure 1.

Based on these ray trajectories and the vertical profiles of temperature, humidity and refractive index structure parameter, EOSTAR calculates the path-integrated and spectrally-resolved transmission, background- and path-radiation, the scintillation, and the blur for a point source at a selected position of a distant point target.
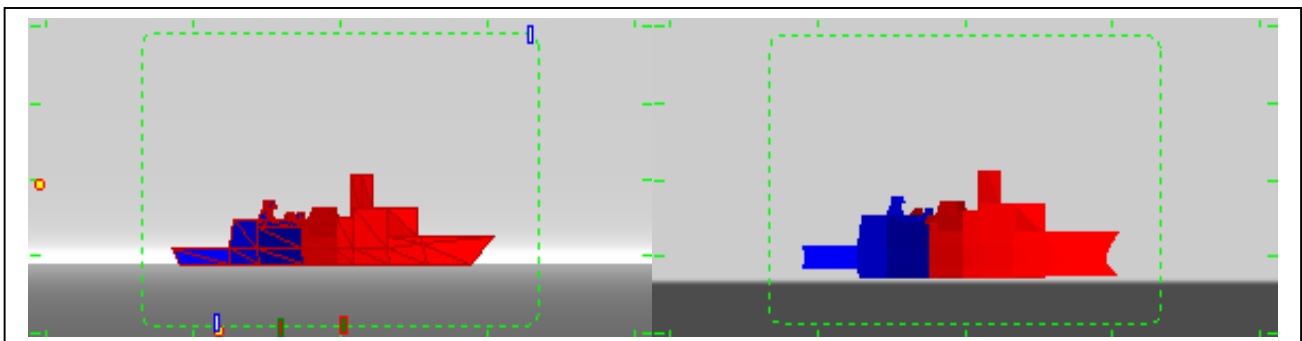

Figure 1: A rendering of a model ship as it appears in an atmosphere-free environment in the left panel. On the right, the same ship image is shown with the inclusion of the refractive inferior mirage effects due to vertical marine refractivity profiles.

Comparison with other experimental data both for geometric effects and turbulence effects is currently underway and is promising. The displacement hull wake model improved the TAWS radiance predictions of MRT from 9.1 to 4.9 percent error and MDT from 8.2 to 4.4 percent error. The planing hull model also performed within ten percent of the measurements. The detection range accuracy was within 15 percent.

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IMPACT/APPLICATIONS

1) The development of realistic models for infrared propagation along low altitude horizontal paths. 2) Evaluation of near-surface paths for laser vibrometry remote sensing laser radars, and high-energy lasers. 3) Performance prediction for infrared and other electro-optical sensors in realistic environments. This will permit the development of sensor equipment better suited to the tasks at reasonable costs. Better performance prediction will also permit real-time assessment of sensor capabilities, which can be used in sensor resource management or incorporated into doctrine. 4) When combined with a target signature and background model, the EOSTAR model suite will be a full electro-optical tactical decision aid.

The wake model and the horizon line-of-sight (HLOS) effort are keeping TAWS current with the state-of-the-art sensor and battlespace requirements. TAWS was used extensively during Operation Iraqi Freedom with high scores for impacting success.

TRANSITIONS

Both the displacement and planing hull wake models were transitioned to the fleet release, TAWS 4.0.

RELATED PROJECTS

The near-wake task is also tied to a larger 6.2/6.4 EO Rapid Transition Proposal (RTP) in conjunction with NRL Monterey. The wake-enabled targets are now being used by the Coast Guard for drug interdiction and homeland defense missions. The scene rendering complement to TAWS called Infrared Target Scene Simulation software (IRTSS) will incorporate the TAWS ocean and target models. The range predictions from TAWS are also presented as overlays to the Pilot's Flight Planning Software (PFPS). Future inputs for better visibility, optical depth, and transmission will come from the NRL Aerosol Analysis and Prediction System (NAAPS).

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